ROOFTOP RUNOFF MANAGEMENT BMPs

Rooftop runoff management BMPs refers to a series of techniques, which involve modifications to conventional building design, that retards, and in some cases treats runoff originating from roofs. The modifications include vegetated roof covers, roof gardens and meadows, and roof ponding areas. Figures 1a, b and c, illustrate some examples of rooftop garden technologies currently in use in Germany.

Roofs are one of the most important sources of concentrated runoff from developed sites. If runoff is retarded at the source, the size of other BMPs throughout the site can generally be significantly reduced in size. Rooftop runoff management effectively increases the time of concentration of runoff derived from roofs, delaying runoff peaks and lowering runoff discharge rates. In highly urbanized areas, rooftop measures may be the only practical alternative for relieving pressure on overtaxed storm sewer systems.

Managing rooftop runoff is of the greatest benefit in highly urbanized settings where space for other BMPs is limited. In addition to achieving specific stormwater runoff management objectives, rooftop runoff management is also aesthetically and socially beneficial. Rooftop runoff management measures are suitable for flat or gently sloping roofs. Nevertheless, engineers should check the runoff curve number in TR-20 calculations and/or Manning roughness factor calculations to determine the effect of the runoff rates on rooftop flow. Furthermore, rooftop runoff management techniques can be retrofitted to most conventionally constructed buildings. Rooftop management, particularly roof gardens, can be effectively used to address the heat island effect of large metropolitan centers.

Vegetated Roof Covers

Vegetated roof covers, also called green roofs and extensive roof gardens, involve blanketing roofs with a veneer of living vegetation. Vegetative roof covers are particularly effective when applied to extensive roofs, such as those that typify commercial and institutional buildings. The filtering effect of vegetated roof covers results in a roof discharge that is free of leaves and roof litter, and therefore is recommended where roof runoff will be directed to infiltration or other water quality management BMPs such as, bioretention cells, dry wells, infiltration trenches and sand filters.

Because of recent advances in synthetic drainage materials, vegetated covers are now feasible on most conventional flat roofs. An efficient drainage layer is placed between the growth media and the roof surface. This layer rapidly conveys water off of the roof surface and prevents water from “laying” on the roof. In fact, vegetated roof covers can be expected to protect roof materials and prolong their life.

Figure 1a

Figure 1b

Figure 1c

Figures 1a,b,c. Examples of rooftop garden technology in Germany.

Vegetated roof covers are an effective means of retarding runoff from roof surfaces.

Initially during a rainfall event, nearly all precipitation striking the foliage is intercepted. As rain continues, water percolates into and begins to saturate the growth media and root zone of the cover. Not until the field capacity of the media is overcome will significant quantities of water begin to drain from the roof. For small rainfall events, little runoff will occur and most of the precipitation eventually will return to the atmosphere by evaporation and transpiration. For larger storms, vegetated roof covers can delay and attenuate the runoff peak significantly.

If materials are selected carefully to reduce the weight of the system, vegetated roof covers generally can be created on existing flat roofs without additional structural support. Drainage nets or sheet drains constructed from lightweight synthetic materials can be used as underlayments to carry away water and prevent ponding. Frequently, the total load of a fully vegetated and saturated roof cover system actually will be less than the design load computed for gravel ballast on conventional tar roofs. A structural engineer should check the capability of the roof to carry the load.

Although vegetative roof covers are most effective during the growing season, they also are beneficial during the winter months if the vegetative matter from the dead or dormant plants is left in place and intact.

Roof Gardens / Meadow

Vegetated roof covers blanket an entire roof area and, although presenting an attractive vista, generally are not intended to accommodate routine traffic by people. Roof gardens, on the other hand, are landscaped environments, which may include planters and potted shrubs and trees. Roof gardens can be tailor-made natural areas, designed for outdoor recreation, and perched above congested city streets. Because of the special requirements for access, structural support, and drainage, roof gardens are found most frequently in new construction. The services of a Professional Engineer will be required to evaluate the architectural and engineering constraints associated with roof garden design.

Roof Ponding Areas

Roof ponding is applicable where the increased load of impounded water on a roof will not increase the building costs significantly or require extensive reinforcement. Roof ponding generally is not viable for large-area commercial buildings where clear spans are required. Special consideration must be given to ensuring that the roof will remain watertight under a range of adverse weather conditions. Low-cost plastic membranes can be used to construct an impermeable lining for the containment area.

Flat roofs can be converted to ponding areas by restricting the flow to downspouts. Figure 2 shows a simple device that can be used to modify downspout inlets. The device features drain holes that will retard outflow as the water level rises and a weir ring that will allow free drainage once the design ponding level is attained. Even small ponding depths of 1 or 2 inches can attenuate stormwater runoff peaks effectively for most storms.

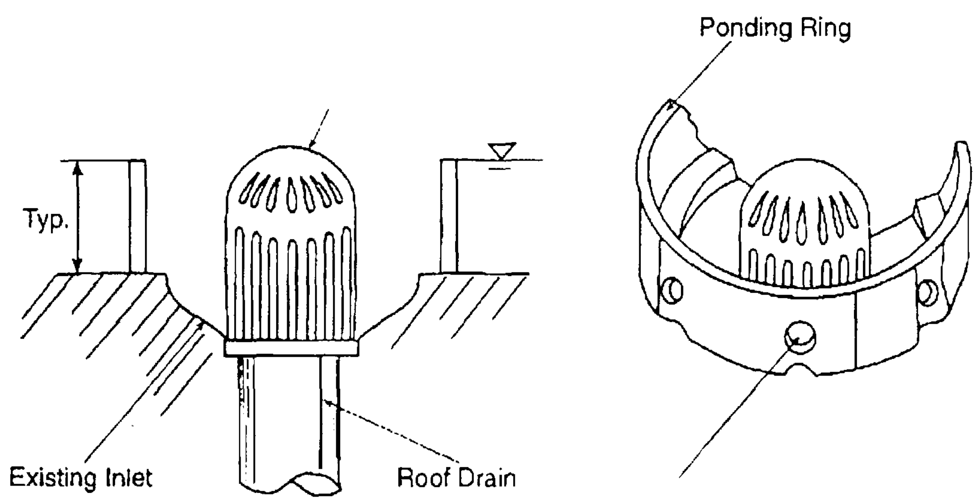


Figure 2. Modification of Downspout Inlet (Adapted from Tourbier, 1974).

Design Criteria for Rooftop Management BMPs

The requirements for regulatory compliance are described in the Design Manual. Of the five sizing criteria in the unified sizing criteria described in the manual, rooftop storage can be used to meet the storage volume requirements for channel protection, Cpv; overbank protection, Qp; and flood protection Qf. It is not anticipated that rooftop storage will be able to address the requirements for water quality control, WQv, or groundwater recharge. Vegetated roof cover may meet water quality, WQv, requirements. Guidelines for coupling roof covers and gardens with runoff treatment and disposal areas which can address the water quality and groundwater recharge criteria are provided separately in this section under, “Rooftop Runoff Treatment and Disposal.”

The performance-based guideline of rooftop management BMPs measures primarily runoff peak attenuation. The methods for evaluating the peak attenuation properties of these measures are based on approaches used for other runoff peak attenuation BMPs, and are described in the Design Manual.

Runoff peak attenuation design storms larger than the 2-year return frequency event are generally not used in designing vegetated roof covers. However, vegetated roof covers will contribute to the attenuation of runoff peaks from larger storms, and should be taken into account when sizing related runoff peak attenuation BMPs at a site. The emphasis of the design should be promoting rapid roof drainage and minimizing the weight of the system. By using appropriate materials, the total weight of fully saturated vegetated roof covers can readily be maintained below 20 pounds per square foot (psf). At present, because most of the pioneering work has been done in Europe, many of the engineering design manuals are not yet available in English. Because of the many factors that may influence the design of vegetated roof covers, it is advisable to obtain the services of installers that specialize in this area. All vegetated roof covers share certain common design elements:

- Impermeable Lining - Must be 'root-proof' unless an additional roof barrier membrane is introduced to prevent root penetration. Various systems are acceptable, but not 'built-up' tar roofs.

- Drainage Net or Sheet Drain - The drainage net or sheet drain is a continuous layer that underlies the entire cover system. A variety of lightweight, high-performance drainage products will function well in this environment. The product selected should be capable of conveying the discharge associated with the runoff peak attenuation storm without ponding water on top of the roof cover. The drainage layer must have a good hydraulic connection to the roof gutters, drains, and downspouts.

- Geotextile – A geotextile layer prevents the growth media from penetrating and clogging the drainage layer. The geotextile should be installed immediately over the drainage net or sheet drains. Many vendors will bond the geotextile to the upper surface of the drainage material.

- Lightweight Growth Media - The depth of the growth media should be kept as small as the cover vegetation will allow. Typically, a depth of 3 to 4 inches will be sufficient. Low-density substrate materials with good water-retention capacity should be specified. Examples are mixtures containing crushed pumice and terra cotta. Media that are appropriate for this application will retain 40 to 60 percent water by weight and have bulk dry densities of between 35 and 50-lb/cubic feet (ft^3). Earth and topsoil are too heavy for most applications.

- Adapted Plants and Grasses - A limited number of plants can thrive in the roof environment where periodic rainfall alternates with periods that are hot and dry. Effective plant species must include the following capabilities:

    1. Tolerate mildly acidic conditions and poor soil,
    2. Prefer very-well-drained conditions and full sun,
    3. Tolerate dry soil, and
    4. Be vigorous colonizers.

Both annual and perennial plants can be used. Dozens of species have been successfully field-tested. Among these, some species of sedum *(Sedum)* have been shown to be particularly well adapted. Other candidates include hardy species of sedge *(Carex),* fescue *(Festuca),* feather grass *(Stipa),* and yarrow *(Achillea).* Vegetative roof covers may include provisions for occasional watering during extended dry periods, conventional lawn sprinklers work well.

Roof gardens generally are designed to achieve specific architectural objectives. The load and hydraulic requirements for roof gardens will vary according to the intended use of the space. Intensive roof gardens typically include design elements such as planters filled with topsoil, decorative gravel or stone, and containers for trees and shrubs. Complete designs also may detain runoff ponding in the form of water gardens or storage in gravel beds. A wide range of hydrologic principles may be exploited to achieve stormwater management objectives, including runoff peak attenuation and runoff volume control.

Effective designs will ensure that all direct rainfall is cycled through one or more devices before being discharged to downspouts as runoff. For instance, rainfall collected on a raised tile patio can be directed to a media-filled planter where some water is retained in the root zone and some is detained and gradually discharged through an overflow to the downspout. Guidelines for coupling roof gardens with treatment and disposal measures are provided separately in this section.

Roof ponding measures can be designed for rainfall events of all sizes. However, the structural loads associated with the impounded runoff may impose limitations on their use. This is especially true if ponding areas must also accommodate runoff derived from adjacent roof surfaces. Devices, such as the one shown in Figure 2, are easily fabricated. However, some form of emergency overflow also is advisable. Emergency overflow can be as simple as a free overfall through a notch in the roof parapet wall.

Many methods can be used for sealing roofs, including tar and mastics or plastic membranes. If membranes are used, their resistance to ultraviolet (UV) radiation, extremes of temperature, and puncture must be known. In most cases, covering the sealing material with a protective layer of gravel or geotextile is advisable.

Roof ponding areas are designed like any other above ground impoundment. To evaluate the performance of these measures, an appropriate design storm must be selected and the hydraulic characteristics of the outlet device determined.

All rooftop runoff management measures must be inspected and maintained periodically. Furthermore, the vegetative measures require the same normal care and maintenance that a planted area does. The maintenance includes attending to plant nutritional needs, irrigating as required during dry periods, and occasionally weeding. The cost of maintenance can be significantly reduced by judiciously selecting hardy plants that will out compete weeds. In general, fertilizers must be applied periodically. Fertilizing usually is not a problem on flat or gently sloping roofs where access is unimpeded and fertilizers can be uniformly broadcast. Properly designed vegetated roof covers should not be damaged by treading on the cover system. Maintenance contracts for the routine care of the vegetative cover frequently can be negotiated with the installer.

When retrofitting existing roofs, preserve easy access to gutters, drains, spouts, and other components of the roof drainage system. It is good practice to thoroughly inspect the roof drainage system quarterly. Foreign matter, including leaves and litter, should be removed.

Roofs that are sheltered by vegetative covers have long life expectancies compared to conventional tar roofs that are exposed to UV and extremes of temperature.

Vegetative roof covers can reduce bare roof temperatures in summer by as much as 40 percent. Because of the insulating properties of the covers, significant saving in both heating and cooling energy is achievable. The savings in energy costs and the extended life of the roof will frequently offset the additional capital costs of vegetated roof covers. Vegetative roof covers are a proven technology in central Europe where urban population density is higher than in most American cities. Several European cities, in an effort to reduce the overloading of sewer systems, provide incentives for homeowners to install vegetated roof covers or roof gardens. Some of the cities are Stuttgart, West Berlin, Cologne, Dusseldorf, and Hamburg.

Roof gardens, vegetated roof covers, and vegetated facades add aesthetic value to residential and commercial property. In addition to the attractive textures and colors of the foliage, these natural urban islands attract songbirds, bees, and butterflies. Although the methods should not be used as water quality measures, they will benefit water quality by reducing the acidity of runoff and trapping airborne particulates.

Specifications and Methodology

Vegetative roof covers influence the runoff hydrograph in two ways:

- Intercept rainfall during the early part of a storm.
- Limit the maximum release rate.

Hydrologic properties are specific to the growth medium. If the supplier does not provide information, prospective media should be laboratory tested to establish:

- Porosity,
- Moisture content at field capacity,
- Moisture content at the wilting point (nominally 0.33 bar), and
- Saturated hydraulic conductivity.

Rainfall retention properties are related to field capacity and wilting point. Appropriate media for this application should be capable of retaining water at the rate of 40 percent by weight, or greater. The media must be uniformly screened and blended to achieve its rainfall retention potential. During the early phases of a storm, the media and roof systems of the cover will intercept and retain most of the rainfall, up to the retention capacity. For instance a 3-inch cover with 40 percent retention potential will effectively control the first 0.6 inches rainfall. Although some water will percolate through the cover during this period, this quantity generally will be negligible compared to the direct runoff rate without the cover in place.

Once the field capacity of the cover is attained, water will drain freely through the media at a rate that is approximately equal to the saturated hydraulic conductivity for the media. Through the selection of the media, the release rate from the roof can be controlled. The media is a mechanism for "buffering" or attenuating the peak runoff rates from roofed areas. The attenuation can be important even for large storms. By using specific information about the hydraulic properties of the cover media, the effect of the roof cover system on the runoff hydrograph can be approximated with numerical modeling techniques. As appropriate, the predicted hydrographs can be added into site-wide runoff models to evaluate the effect of the vegetative roof covers on site runoff. The hydraulic analysis of roof covers will require the services of a Professional Engineer who is experienced with drainage design.

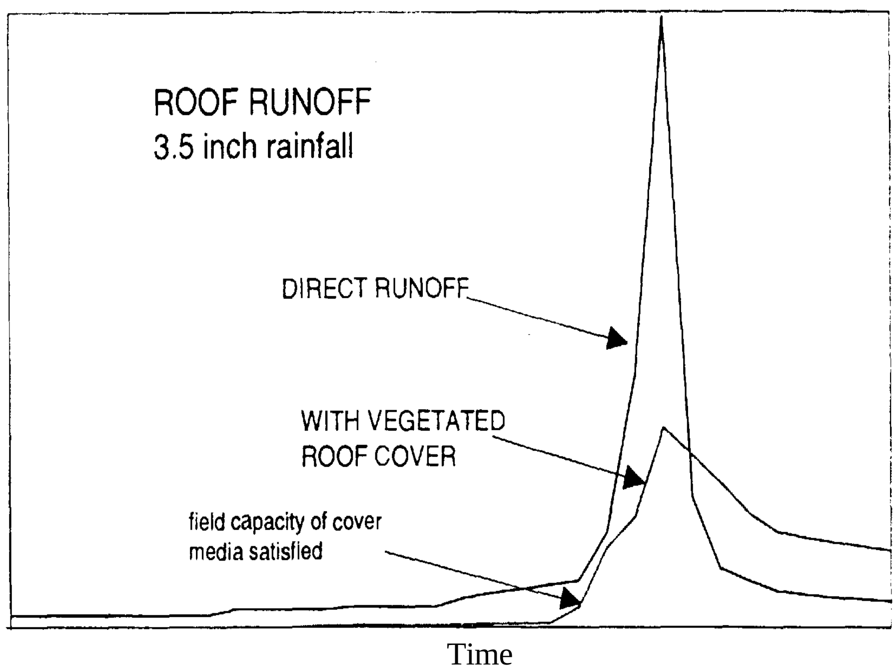


Figure 4. Influence of vegetated roof cover on runoff hydrograph.

Drainage nets or sheet drains with transmissivities of 15 gallons per minute per foot, or larger, are recommended. When evaluating a drainage layer design, the roof topography should be evaluated to establish where the longest travel distances to a roof gutter, drain, or downspout occur. If flow converges near drains and gutters, the design unit-flow rate should be increased accordingly. The drainage layer should be able to convey the design unit flow rate at the roof grade without water ponding on top of the cover media. For larger storms, direct roof runoff is permitted to occur. The design flow rates should be based on the largest runoff peak attenuation design storm considered in the design of the vegetated roof cover.

The net weight of the fully vegetated roof cover should be compared against the design loads for the roof. Preliminary designs commonly are too light to satisfy the ballast requirements for flat tar roofs. As required, deepening the media can increase the weight of the cover system. In Baltimore, the maximum roof design loads must incorporate expected snow accumulation. The design snow load should be added to the weight of the roof system.

The analysis of roof ponding systems is very similar to the design of dry ponds and other runoff peak attenuation facilities. The procedure for storage routing is described in TR-55. The necessary data that the input hydrograph needs are:

1. Depth-storage function, and
2. Depth-discharge function.

Because the roof is impermeable, the runoff hydrograph is simply the rainfall distribution for the design storm multiplied by the area of the roof. The depth to storage relationship can be computed from the topography of the roof. For perfectly flat roofs, the storage volume of a ponding level is equal to the roof area times the ponding level. The depth-discharge relationship will be unique to the outlet device used. For simple ponding rings, the discharge rate will approximately equal:

$$O = C \times 3.141 \times D \times (d-H)^{3/2}$$

where:

O	=	outflow rate
D	=	diameter of the ring
d	=	depth of ponding
H	=	height of the ring
C	=	discharge coefficient (3.22)

With this information, the attenuation effectiveness of the roof ponding system can be predicted by using the Modified Puls or other storage-routing procedure. The performance of the ponding area can be adjusted by changing the height or diameter of the ponding ring or by modification of the optional weirs.

It should be noted that the potential deflection of the roof must be taken into account for the design volume.

Rooftop Runoff Treatment and Disposal

Rooftop runoff treatment and disposal is the handling of rooftop runoff by systems and techniques that avoid or replace direct connections of roof drainage systems to storm or sanitary sewer systems. This may be applicable wherever direct connection of roof drainage systems to public sewer, storm sewer or stormwater management systems exists or is planned.

In many urban areas, roof drainage systems are connected directly to sewer systems to reduce the inconvenience to property owners of excess surface runoff. Such connections may be permitted, or they may be illicit connections made for the convenience of property owners without consideration of the effects on public sewer systems. Flooding of street and road areas may result with accompanying hazards to health and safety.

Maintenance for infiltration and storage of runoff is covered in the Design Manual.

Four techniques are described below for handling rooftop runoff without direct connections. Depending upon the size of rooftops and local rainfall conditions, these techniques can be sued singly or in combination to achieve the desired results.

1. Surface Drainage - The simplest and most widely used technique for disposing of rooftop runoff is to allow it to disperse over the surface of the land. This technique is especially applicable where there is sufficient open space and permeable soils to allow infiltration of surface runoff to occur. This practice is often avoided where property owners fear flooding, excessive surface ponding, or erosion from concentrated runoff. However, if proper precautions are taken, the practice can usually be used without significant problems. The Design Manual provides guidance for the disconnection of rooftop runoff in Section 5.2 of the Manual under " Disconnection of Rooftop Runoff Credit".

2. Subsurface Infiltration - Where surface drainage of rooftop runoff is not feasible the use of subsurface infiltration practices may become a suitable alternative. Exfiltration trenches may be installed to dispose of rooftop runoff beneath the land surface. Of course, soils must have a relatively high permeability in order for these systems to function properly. As with surface drainage, adequate precautions should be taken to prevent flooding. Design, construction and maintenance criteria for subsurface retention devices are provided in the Design Manual in Section 3.3 "Stormwater infiltration". Typical applications of subsurface infiltration techniques for rooftop runoff disposal are illustrated in Figures 5 and 6.

3. Runoff Collection and Storage - In certain circumstances, neither surface drainage nor would subsurface infiltration techniques be feasible because of poor soils or other site conditions.

A suitable alternative may be to collect and store rooftop runoff for later release or use. Rain barrels at downspout outlets are an example of how this technique has been applied in the past. Aboveground storage facilities such as rain barrels, however, are generally not desirable in densely urbanized areas. One solution may be to install cisterns underground to collect the water. The stored water can be utilized for some purpose, which does not require treated water, such as garden or lawn watering. The benefit of the cistern system will be a reduction of the sediment and pollutants from rooftop runoff. The use of the withheld water is for lawns and other non-potable uses. A typical application of a cistern for rooftop runoff collection is illustrated in Figure 7.

4. Dripline Planters - The description of dripline planter BMPs refers to a number of landscaping features that can be placed to receive runoff from roofs to water vegetation. Possible configurations include foundation plantings below the edge of the roof or above ground box planters along the side of a building. Figure 8 illustrates a typical application of dripline technology.

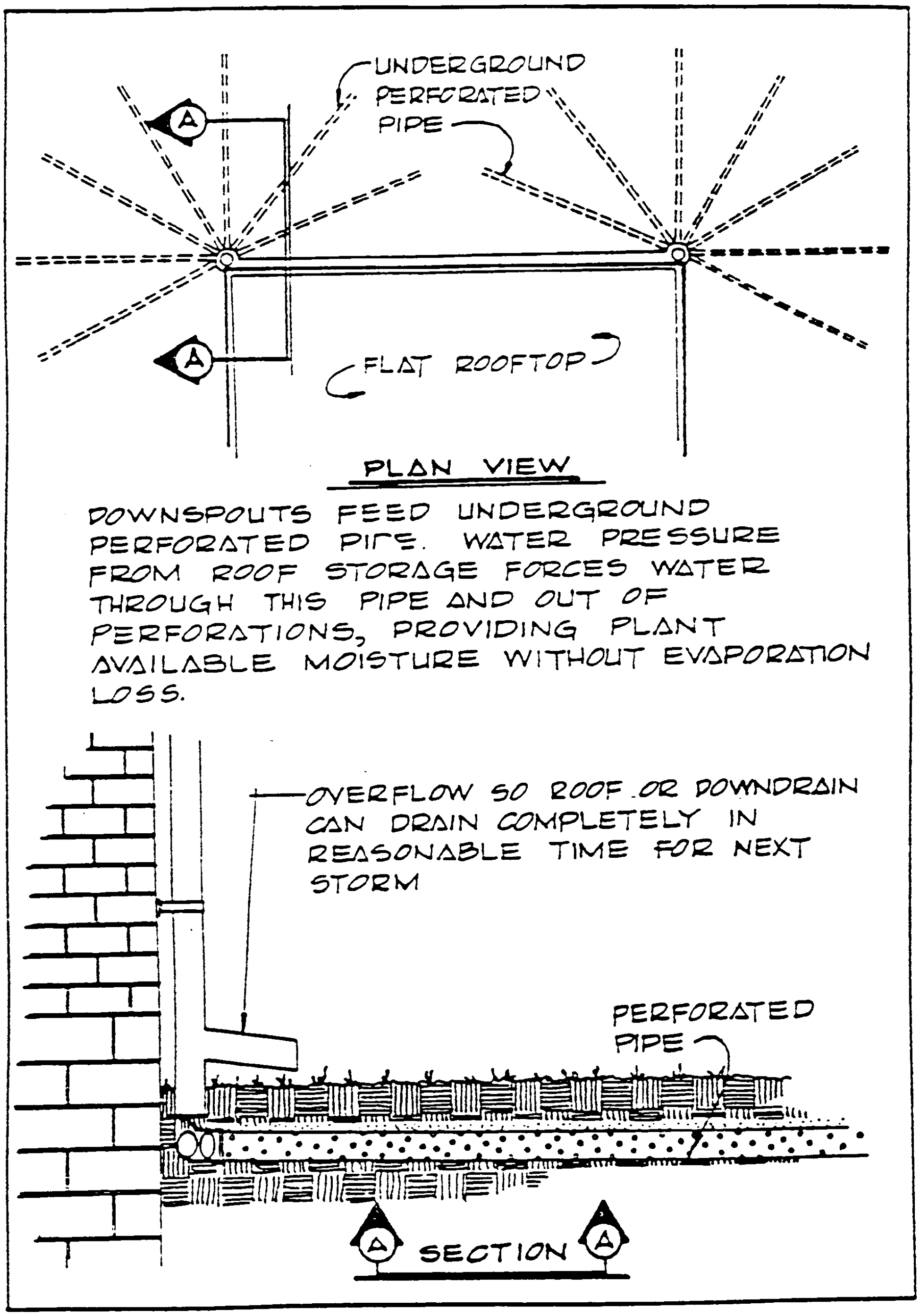
   The design characteristics of dripline planter BMPs are runoff can be conveyed to the planter from downspouts or directly as a spray using rain dispersers instead of gutters. Additional storage can be obtained placing a coarse medium at the bottom of the box planter. The volume of the planter should be estimated according to the area of the roof. If using foundation plantings, care must be exercised to avoid leakage into basements. Figure 9 illustrates design characteristics of dripline planter technology.

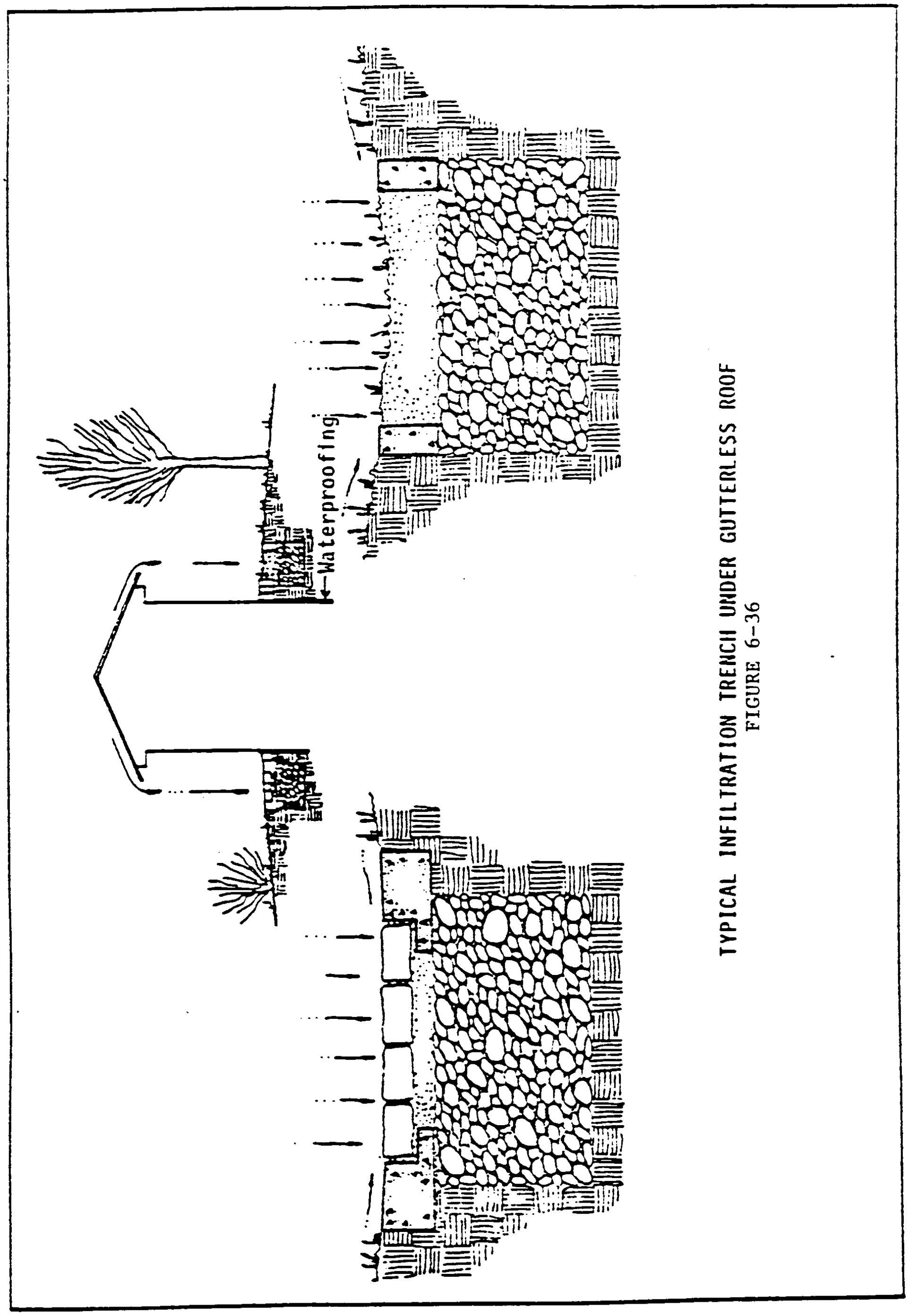
   Dripline planter BMPs can be applied in new, existing developments and in virtually any type of building.

   Sources for Additional Information: SaveTime Corp. (2000), "RainhandleR " http://www.rainhandler.com/ (September 20, 2000).

Figure 5. Infiltration Drainage of Rooftop

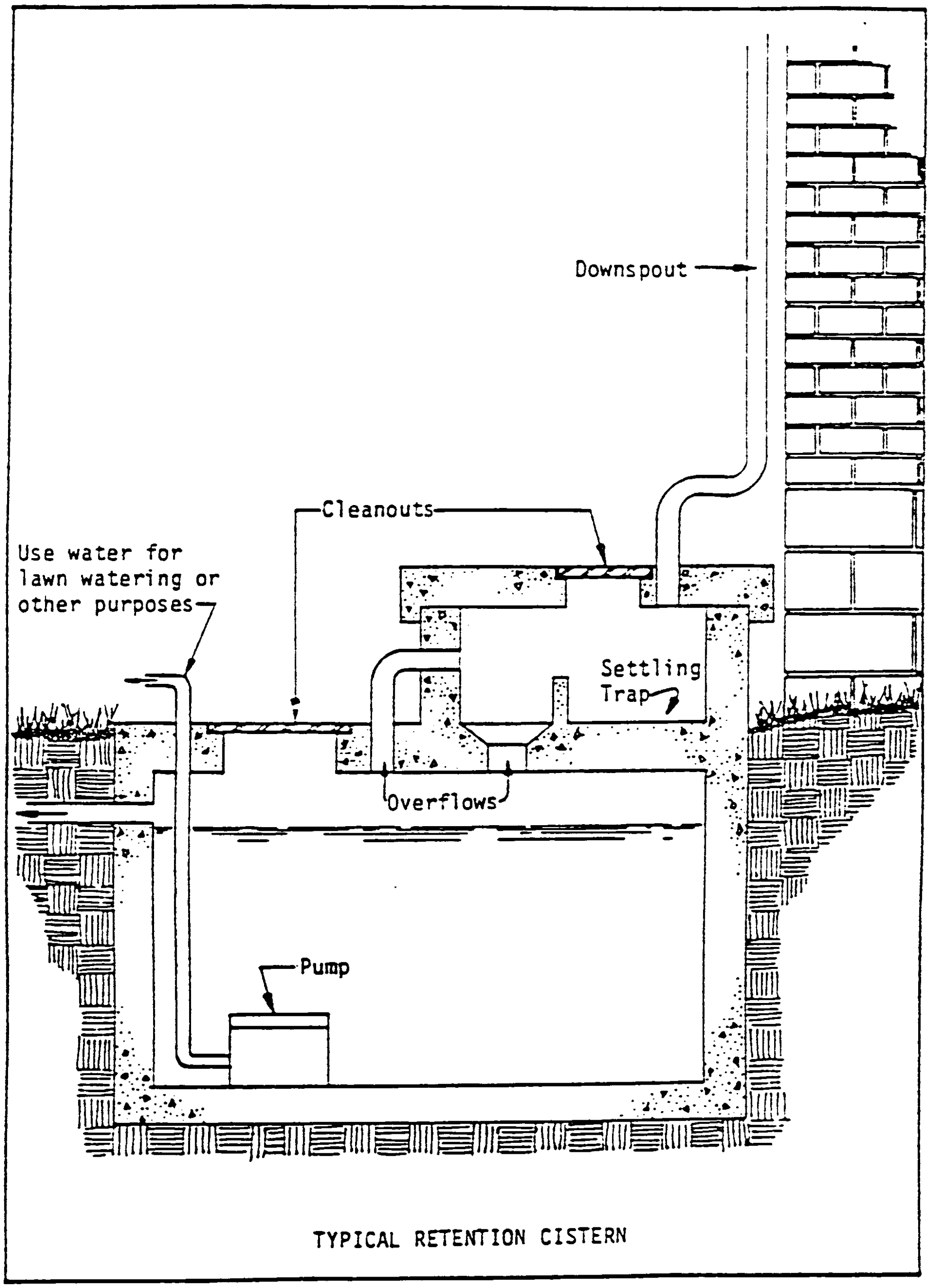
INFILTRATION DRAINAGE OF ROOFTOP





Source: Virginia Soil and Water Conservation Commission

Figure 6. Typical Infiltration Trench Under Gutterless Roof



Source: Virginia Soil and Water Conservation Commission

Figure 7. Typical Retention Cistern

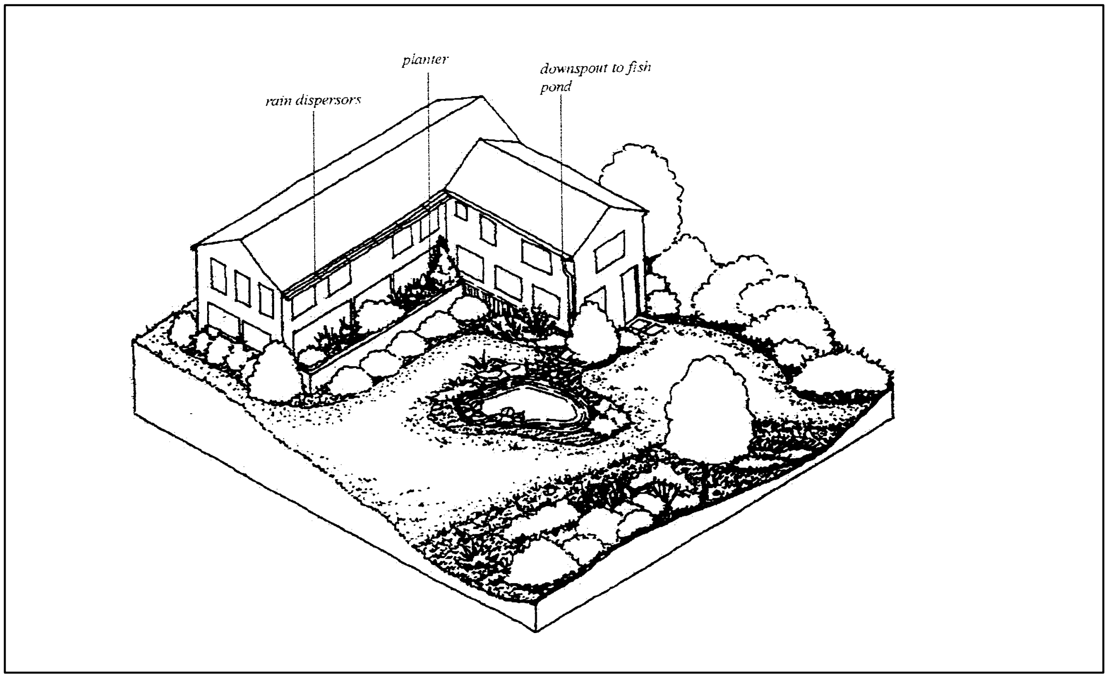


Figure 8. Dripline Planters

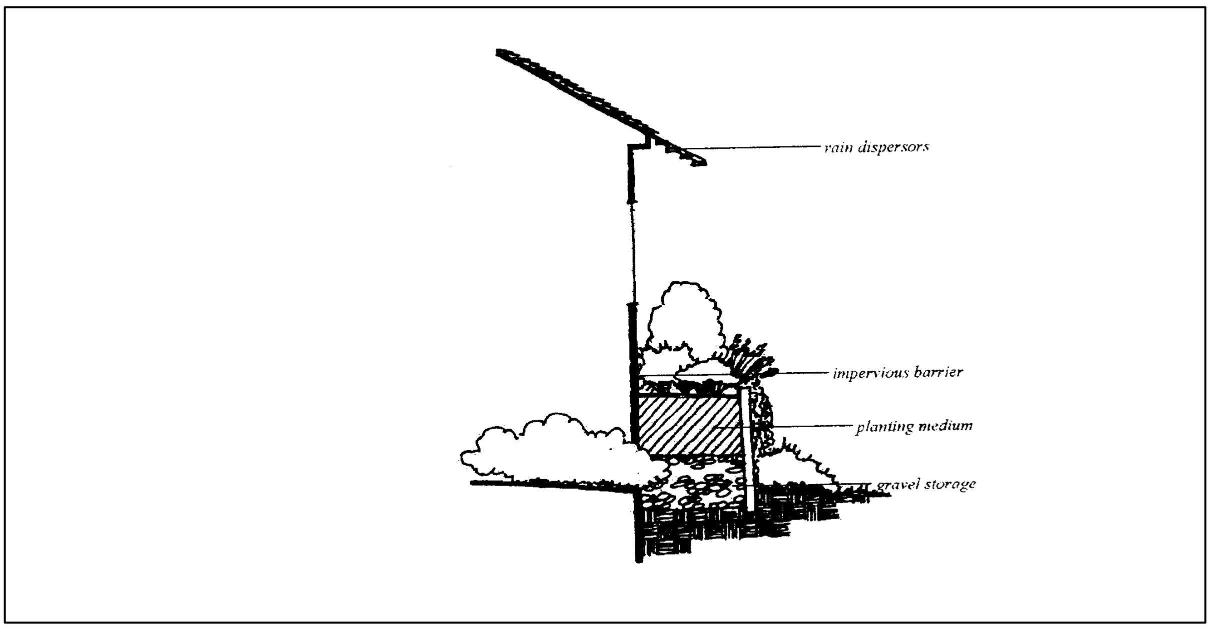


Figure 9. Dripline Planter Detail